VISIT…

11 Introduction to Engineering Maintenance

11.1 NEED FOR MAINTENANCE

Each year billons of dollars are spent on engineering equipment maintenance worldwide, and today's maintenance practices are market driven, in particular for the manufacturing and process industry, service suppliers, and so on [1]. Because of this, there is a definite need for effective asset management and maintenance practices that can positively influence success factors such as price, profitability, quality, reliable delivery, safety, and speed of innovation.

In the future engineering equipment will be even more computerized and complex. Further computerization of equipment will increase the importance of software maintenance significantly, approaching, if not equaling hardware maintenance. In addition, factors such as increased computerization and complexity will result in greater emphasis on maintenance activities with respect to areas such as cost effectiveness, quality, safety, and human factors [2]. In the future creative thinking and new strategies will definitely be required to realize all potential benefits and turn them into profitability.

11.2 FACTS AND FIGURES RELATED TO ENGINEERING MAINTENANCE

Some of the facts and figures concerning engineering maintenance are as follows:

- U.S. industry spends over $300 billion annually on plant maintenance and operations [3].
- It is estimated that the cost of maintaining a military jet aircraft is approximately $1.6 million per year, and about 11% of the operating cost for an aircraft accounts for maintenance activities [4].
- Over the years the size of a plant maintenance group in a manufacturing organization has varied from 5 to 10% of the total operating force [5] — 1 to 17 persons in 1969 and 1 to 12 persons in 1981 [5].
- For fiscal year 1997, the request of the U.S. Department of Defense for their operation and maintenance budget was $79 billion [6].

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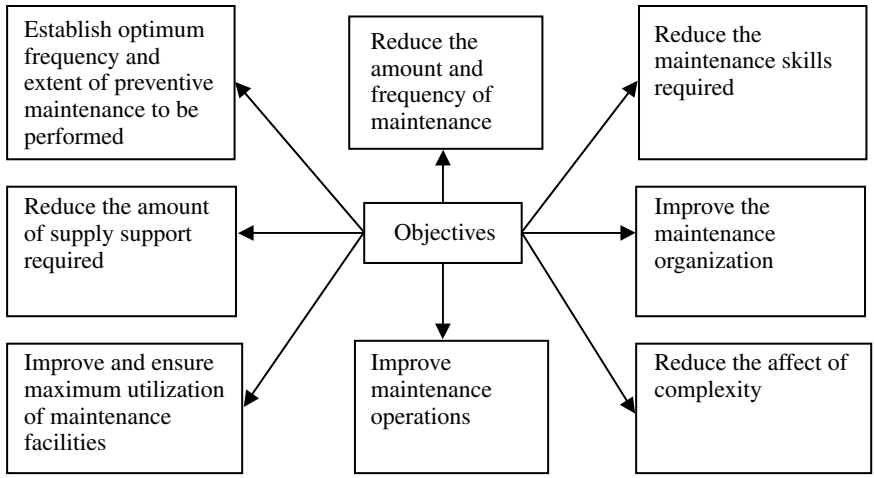
Establish optimum frequency and extent of preventive maintenance to be performed
Reduce the amount and frequency of maintenance
Reduce the maintenance skills required
Reduce the amount of supply support required
Objectives
Improve the maintenance organization
Improve and ensure maximum utilization of maintenance facilities
Improve maintenance operations
Reduce the affect of complexity

FIGURE 11.1 Important objectives of maintenance engineering.

- In 1970 a British Ministry of Technology Working Party document reported that the United Kingdom annual maintenance cost was around 3000 million pounds [7,8].
- The U.S. Department of Defense spends approximately $12 billion annually on depot maintenance of weapon systems and equipment [9].

11.3 MAINTENANCE ENGINEERING OBJECTIVES

There are many objectives of maintenance engineering. Some of the important ones are shown in Figure 11.1 [10].

11.4 MAINTENANCE-RELATED DATA INFORMATION SOURCES

There are many sources for obtaining maintenance-related data. Table 11.1 presents five such sources.

11.5 MAINTENANCE MEASURES

Many indexes to measure maintenance activity performance have been developed. Usually, the values of these indexes are calculated periodically to monitor their trends or compare them with established standard values. This section presents some of these indexes [5,11–13].

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TABLE 11.1
Sources for Obtaining Maintenance-Related Data

No.	Source Name and Address
1	National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA
2	GIDEP Data, Government Industry Data Exchange Program (GIDEP) Operations Center, Fleet Missile Systems, Analysis, and Evaluation Group, Department of Navy, Corona, CA
3	Reliability Analysis Center, Rome Air Development Center, Griffis Air Force Base, Rome, NY
4	Defense Technical Information Service, DTIC-FDAC, 8725 John J. Kingman Road, Suite 0944, Fort Belvoir, VA
5	Data on Trucks and Vans, Commanding General, Attn: DRSTA-QRA, U.S. Army Automotive-Tank Command, Warren, MI

11.5.1 Index 1

This index relates the maintenance cost to the total investment in plant and equipment and is defined by

$$I_{mi} = \frac{C_m}{C_i} \tag{11.1}$$

where I_{mi} is the index parameter, C_m is the total maintenance cost, and C_i is the total amount of investment in plant and equipment.

The approximate average values for this index in the chemical and steel industries are 3.8 and 8.6%, respectively.

11.5.2 Index 2

This index measures the maintenance budget plan accuracy and is defined as follows:

$$I_{ab} = \frac{C_{am}}{C_{bm}} \tag{11.2}$$

where I_{ab} is the index parameter, C_{bm} is the budgeted maintenance cost, and C_{am} is the actual maintenance cost.

Large variances in the values of this index indicate the need for immediate attention.

11.5.3 Index 3

This index relates the maintenance cost to the total sales revenue and is defined as follows:

$$I_{ms} = \frac{C_m}{C_{Sr}} \tag{11.3}$$

where I_{ms} is the index parameter and C_{Sr} is the total sales revenue.

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According to some documents, the average expenditure of the maintenance activity for all industry is around 5% of sales revenue. However, there is a wide variation among industries. For example, the expenditure for the maintenance activity for chemical and steel industries is around 6.8% and 12.8% of sales revenue, respectively.

11.5.4 Index 4

This index relates maintenance cost to total man-hours worked and is defined as follows:

$$I_{mm} = \frac{C_m}{C_{mh}} \tag{11.4}$$

where I_{mm} is the index parameter and C_{mh} is the total number of man-hours worked.

11.5.5 Index 5

This index relates the total maintenance cost to the total output (i.e., in units such as tons and megawatts) by the organization in question and is defined by

$$I_{mo} = \frac{C_m}{T_o} \tag{11.5}$$

where I_{mo} is the index parameter and T_o is the total output by the organization in question, expressed in units such as tons, megawatts, and gallons.

11.5.6 Index 6

This index relates the total maintenance cost to the total manufacturing cost and is defined as follows:

$$I_{mtm} = \frac{C_m}{C_{tm}} \tag{11.6}$$

where I_{mtm} is the index parameter and C_{tm} is the total manufacturing cost.

11.5.7 Index 7

This index is quite useful for measuring inspection effectiveness and is defined as follows:

$$I_{jc} = \frac{TNJRI}{TNIC} \tag{11.7}$$

where I_{jc} is the index parameter, *TNIC* is the total number of inspections completed, and *TNJRI* is the total number of jobs resulting from inspections.

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11.5.8 Index 8

This is an important index used to measure maintenance effectiveness with respect to man-hours associated with emergency and unscheduled jobs and total maintenance man-hours worked. The index is defined by

$$I_{mh} = \frac{TMH_{eu}}{TMH_{w}} \tag{11.8}$$

where I_{mh} is the index parameter, TMH_w is the total number of maintenance man-hours worked, and TMH_{eu} is the total number of man-hours associated with emergency and unscheduled jobs.

11.5.9 Index 9

This index is often used in material control areas and is defined as follows:

$$I_{mc} = \frac{THJ_{pam}}{TJ_{p}} \tag{11.9}$$

where I_{mc} is the index parameter, TJ_{pam} is the total number of planned jobs awaiting material, and TJ_p is the total number of planned jobs.

11.6 SAFETY IN MAINTENANCE

Safety in maintenance is becoming an important issue, as accidents occurring during maintenance work or concerning maintenance are increasing significantly. For example, in 1994 around 13.61% of all accidents in the U.S. mining industry occurred during maintenance work and they have been increasing at a significant rate annually since 1990 [14,15].

Some of the main reasons for safety problems in maintenance are poor safety standards and tools, poor equipment design, poor training of maintenance personnel, insufficient time to perform required maintenance tasks, poorly written maintenance instructions and procedures, poor management, poor work environments, and inadequate work tools [15].

One of the important ways to improve maintenance safety is to reduce the requirement for maintenance as much as possible in products and systems during their design phase. When the need for maintenance cannot be avoided, designers should follow guidelines such as those listed below for improving safety in maintenance [16]:

- Eradicate the need for performing maintenance and adjustments close to hazardous operating parts or equipment.
- Keep design as simple as possible, because complexity usually adds to maintenance problems.
- Aim to eliminate the requirement for special tools or equipment.
- Provide appropriate guards against moving articles or parts and interlocks for blocking accesses to hazardous locations.

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- Incorporate appropriate fail-safe designs for preventing injury and damage if a failure occurs.
- Design for easy accessibility so that items requiring maintenance can easily be checked, removed, replaced, or serviced.
- Develop designs or procedures that minimize the occurrence of maintenance errors.
- Develop the design in a manner that reduces the probability of maintenance personnel being injured by escaping high-pressure gas, electric shock, contact with a hot surface, and so on.
- Incorporate appropriate devices or other measures for early prediction and detection of all potential failures so that the required maintenance can be performed prior to failure with somewhat reduced risk of hazard.

11.7 QUALITY IN MAINTENANCE

Maintenance quality provides some degree of confidence that repaired or maintained items will function safely and reliably [17,18]. Quality in maintenance is very important because poor quality maintenance can lead to severe consequences. For example, the following three tragedies are believed to be, directly or indirectly, the result of poor quality maintenance [15]:

- In 1986 the space shuttle *Challenger* exploded and all seven crew members lost their lives [17–18]. A subsequent investigation identified the cause of the disaster as the failure of the pressure seal in the aft field joint of the right solid rocket motor. Furthermore, the investigation concluded that a high-quality maintenance program would have successfully tracked and discovered the cause of the disaster.
- In 1990 10 people died as the result of a serious steam leak in the fire room on the *U.S.S. Iwo Jima* (LPH2), a U.S. Navy ship [19]. Failure of the service turbine generator root-valve bonnet fastener was identified as the main cause of this tragedy. Further investigation revealed that ship's personnel furnished the replacement fasteners without properly verifying if the requirements of the technical manual and drawings were fully satisfied.
- In 1963 the *U.S.S. Thresher*, a U.S. Navy nuclear submarine, was lost at sea because of flooding in its engine room [17,19]. An investigation identified a piping failure in one of the salt water systems as the most likely cause for the disaster. Consequently, many changes were recommended in the submarine design and maintenance processes.

Past experiences indicate that postmaintenance testing (PMT) is quite useful for increasing the quality of maintenance. Its three main objectives are (a) to ensure that no new deficiencies have been introduced, (b) to ensure that the original deficiency has been eradicated properly, and (c) to ensure that the item in question is ready to carry out its stated mission [20]. In order to increase the quality of maintenance, PMT should not only be performed after all corrective maintenance

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activities but also after some preventive maintenance activities, as considered appropriate.

11.8 PROBLEMS

1. Discuss the need for maintenance.
2. Discuss at least five facts and figures concerning engineering maintenance.
3. What are the important objectives of maintenance engineering?
4. List at least three maintenance-related data information sources.
5. In your opinion, what is the most important maintenance index or measure?
6. Discuss two general maintenance indexes.
7. Discuss the importance of safety in engineering maintenance.
8. Discuss the need for quality in maintenance activities.
9. List at least nine useful guidelines for equipment designers to improve safety in the maintenance activity.
10. What are the important causes of safety problems in engineering maintenance.

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